SCIENCE FOR GLASS PRODUCTION

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LASER ETCHING AND POLISHING OF QUARTZ TUBES

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A technology and a plant for laser etching and polishing of quartz tubes are considered, which makes it possible to remove the surface layer of impurities and cracks and polish the tube surface without a direct contact. This technology provides for improved quality of tubes for diffusion furnaces and ultraviolet illuminators.

Use of highly intense laser radiation to treat articles of high-melting oxide compounds is accompanied by thermophysical effects that are hard to attain using other heating methods. A typical example of such an application is treatment of quartz glass by CO_2 laser radiation (10.6 μm).

Quartz glass has a unique combination of characteristics: a high melting temperature, substantial heat and chemical resistance, and optical transparency, which allows for a wide application of this material in various sectors of industry from fiber optics to chemical engineering [1]. Accordingly, a search for new methods for treating quartz glass is still topical. One such method involves radiation of a CO_2 laser used in different technologies: from cutting and welding of quartz glass to drawing fiberoptic light guides [2, 3]. These processes are based on the effect of intense absorption of 10.6-micrometer radiation in quartz glass (the thickness of the absorption layers is ≤ 10 μm). By varying the intensity and duration of CO_2 laser radiation of quartz glass, it is possible to achieve various stages of treatment: from simple heating to evaporation of glass. An important advantage of laser technology is the fact that the object heated is not contaminated by the heat source, which makes it possible to treat or produce high-purity articles [3].

For instance, Dianov et al. [3] used laser radiation to draw high-purity fiberoptic quartz light guides. The intermediate product was heated to a viscous state and at the same time the upper defective layer of glass evaporated, which made it possible to obtain high-strength light guides. The entire range of thermophysical effects on quartz glass was used.

The purpose of our studies was to analyze the technology and equipment for laser etching and polishing of quartz tubes used, for instance, in diffusion furnaces, where high-strength and high-purity quartz tubes are needed. It is known [2 – 4] that the surface layer of quartz glass contains impurities (mostly hydroxyl) and has microcracks which to a large extent determine the quality of quartz products, including tubes, especially in cases where the state of the tube surface affects the processes inside the tube, for instance, using tubes for UV-purification of water (i.e., when good optical properties of tubes are needed) or in high-temperature chemical reactions (i.e., when used in diffusion furnaces [5]).

Chemical etching of the impurity layer with fluoric acid and subsequent fire polishing by hydrogen-oxygen burners are labor consuming and environmentally dangerous processes.

Let us consider the technology of contact-free etching and polishing of quartz tubes using radiation of a CO_2 laser based on using laser radiation of high density (over 10 kW/cm^2), which leads to intense evaporation of the surface layer of glass. Evaporation can reach several hundreds of microns, while the temperature of the tube surface is not high and, consequently, impurities do not diffuse into the glass.

With high density of laser radiation and, accordingly, with a substantial thickness of the layer removed, the glass surface becomes polished due to nonuniform erosion of the surface of the sample section. With an optimally selected radiation intensity and laser-beam displacement velocity, it is possible to implement simultaneously etching (evaporation) and polishing.

Thus, by optimizing the radiation density, it is possible to achieve both highly intense evaporation (i.e., etching) and polishing (a low-viscosity state) of a quartz tube surface.

To implement this technology, quartz tube samples were taken before laser treatment and their surface impurities and microcracks were measured: special polished sections of tubes 80 mm in diameter and 0.5 mm wall thickness were

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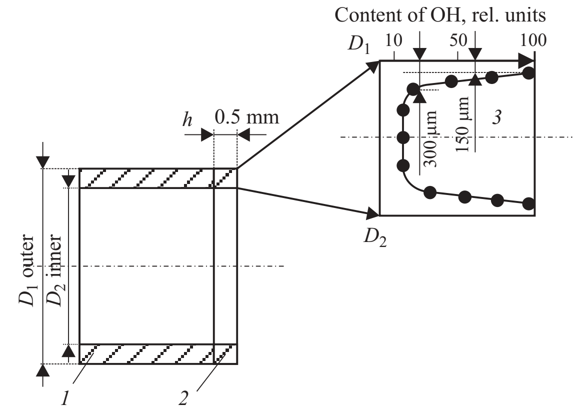

Fig. 1. Distribution of impurities and microcracks across a section of a quartz tube: *1*) pipe; *2*) cross section for analysis; *3*) layer of microcracks (150 μm).

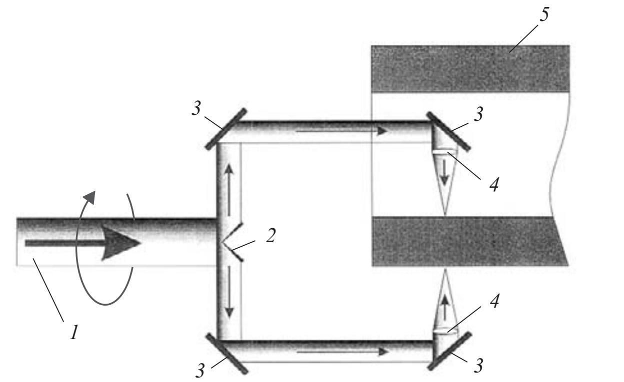

Fig. 2. Optical scheme of the plant for laser etching and polishing of quartz tubes: *1*) ray of CO_2 laser; *2*) separating cone; *3*) mirror; *4*) lens; *5*) quartz tube.

taken to determine the content of hydroxyl by IR spectroscopy (based on the band of 2.7 μm) [3, 4] and the amount of the surface (cracked) damaged layer by fluoric acid pickling [1]. The results of these measurements are shown in Fig. 1. It can be seen that the thickness of the impurity-and-crack-containing layer is about 300 μm. Consequently, to obtain pure quartz tubes, it is necessary to remove a layer about 300 – 350 μm thick.

To implement laser etching and polishing of quartz tubes, a plant based on an optical scheme (Fig. 2) was used.

The schematic design of the plant is shown in Fig. 3. It consists of the following systems:

– system of regulated rotation and linear motion of the quartz tube;

– an optical tract including a CO_2 laser, a beam separator, mirrors, lenses, and structural elements; a CO_2 laser of power 100 W is used;

– a service system consisting of gas supercharging elements for meters, valves, power units, control units, and the controller.

To optimize the technological regime of the plant, a series of operations was carried out, including removal of surface layers of different thickness along the tube, cutting out polished sections, and measuring their content of hydroxyl and the cracked layer. The studies indicated that the concentration of hydroxyl in the surface layer becomes much lower when its thickness is about 300 μm. It should be stressed that each new batch of products requires such calibrations; however, our studies have established that removal of a layer of over 300 μm eliminates the need for calibration, since hydroxyl in glass does not diffuse under laser irradiation.

Detailed studies, such as IR spectroscopy, indicated that the considered method of laser radiation prevents impurities from diffusion and microcracks from propagating (or fusing) into the glass depth, since the processes of evaporation and surface tension proceed at a high rate without a substantial temperature increase along the depth of the glass material, which was corroborated by direct pyrometric measurements.

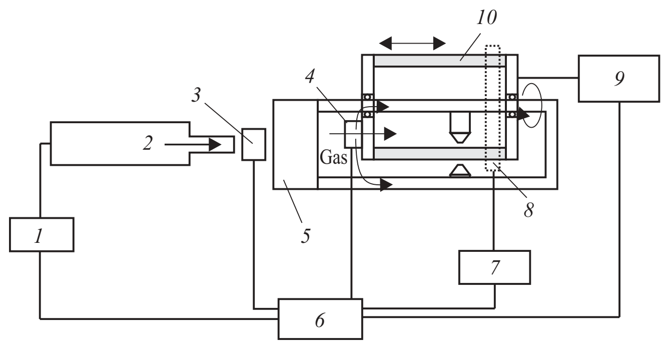

Fig. 3. Schematic design of the plant for treating quartz tubes by laser radiation: *1*) power unit; *2*) ray of CO_2 laser; *3*) optical gate valve; *4*) gas supercharge valve; *5*) optical tract; *6*) controller; *7*) measurement block; *8*) optical meter of diameter; *9*) engine control unit; *10*) quartz tube.

The use of the technology proposed makes it possible to obtain high-quality quartz tubes and provides for a possibility of automation of this technology.

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